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Transition to Detonation in Exploding Bridgewire Detonators

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Abstract

We are investigating using breakout profile measurements and/or Fabry-Perot velocimeter measurements during early stages of initiation in Exploding BridgeWire (EBW) detonators as a tool for understanding the physics of initiation of these devices and as a tool for monitoring aging effects. We believe any changes due to aging may be more readily observed in the very early stages of the initiation. We have developed a method that allows measurement of the detonation velocity, detonation profile and interface velocity as a function of distance from the bridgewire.

Introduction

Little is known about the early stages of transition to detonation in EBW detonators. Detonator performance may be affected over time by physical and chemical changes that may occur under storage conditions. Observing the early stages of the detonation- front evolution may provide a sensitive test to be used as a prediction of reliable service life of the detonator.

In the past there have been no means to investigate the early stages of initiation. We now have a tool, the femtosecond laser, which can section a detonator, leaving a header with a thin layer of HE remaining. By varying the thickness of the HE we can observe the detonation wave at various distances from the bridgewire as it comes to full strength. The femtosecond laser cuts the HE without collateral damage or change in the morphology of the explosive crystals on the cut surface. This is important since we don't want to introduce uncertanties in the results by the method we use to prepare the sample.

The goal of the measurements is to provide information on the details of the run-up to detonation detonators, both old and new. If, for example, the initiation is not uniform over the area of the bridgewire, converging shock waves may cause initiation over a smaller area than expected. This could have implications concerning the marginality of the initiation of the detonator. Density variations, voids or gaps can have the same effect.

Insight gained into the run-to-detonation process will also aid in the development of computer modeling of the detonation. Such codes then can be used to predict the consequences of variation of detonator performance with changes in parameters due to age and handling. This information, in turn, can be used to better develop detonator design and new plastic bonded explosives with improved performance and lower vulnerability to aging effects.

Experimental Approach

We took a two-pronged experimental approach to the problem. The first approach involves observing the breakout profile of the developing detonation wave near the bridgewire. Detonators were sectioned with a high-powered femtosecond laser at various distances from the bridgewire (Fig. 1).

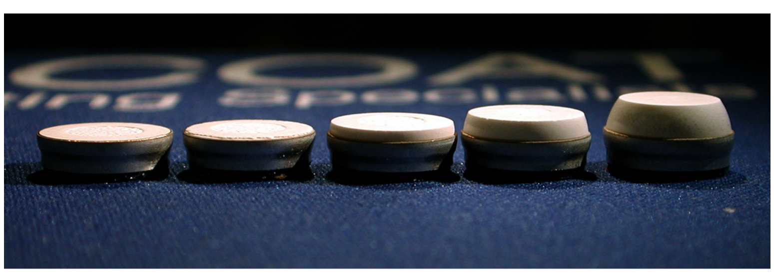

Fig. 1. Hemispherical detonators sectioned at varying distances from the bridgewire.

These detonators were then fired and the detonation profile across the diameter of the exposed surface in a direction parallel to the underlying bridgewire was measured using the technique shown in Fig. 2. The sample was illuminated with a 532 nm laser pulse during the time the wave arrives at the surface. The diffusely reflected light collected from the surface of the detonator was focused onto the photocathode of an electronic streak camera. A narrow bandpass filter (~1 nm) was introduced into the optical path to allow only the reflected laser light to pass through to the streak camera photocathode.

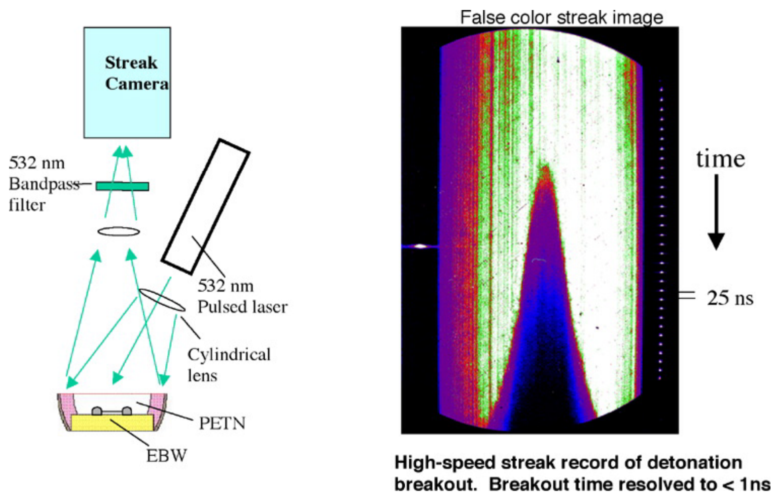

Fig. 2. Experimental setup and sample streak record

As the detonation/shock front arrives at the cut surface the laser light is extinguished, thus giving us a record of the front arrival along the diameter parallel to the bridgewire as a function of time (Fig. 2). Doing this for varying distances from the bridgewire gives us a picture of the developing detonation wave as it moves outward from the bridgewire. We observed the wave at distances from the bridgewire to the cut surface of 0.6mm to 4.0 mm. The detonators consist of a low-density PETN core in contact with the bridgewire, surrounded by an outer layer of PBX-9407 (RDX-94% + Exon 461 binder-6%).

The second approach was to use a Fabry-Perot Velocimeter to measure the velocity induced in a LiF crystal due to the detonation wave at the surface of the PETN. This data gives us an indication of the strength of the detonation wave. This technique is illustrated in Fig. 3.

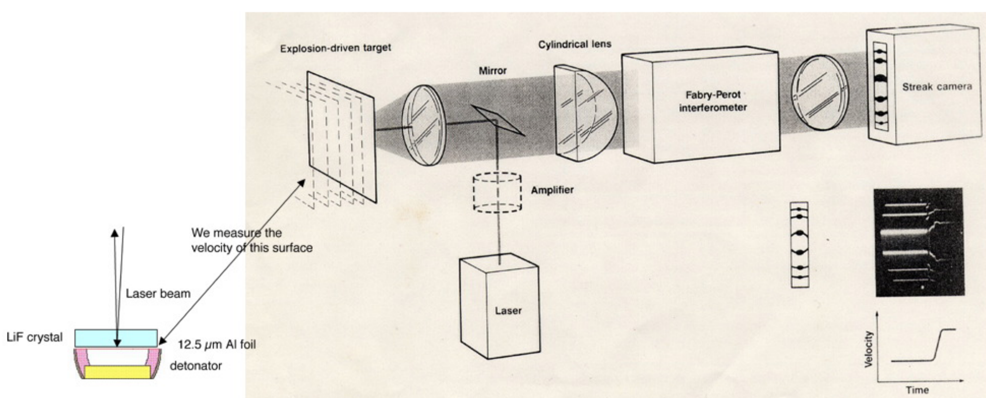

Fig. 3. Fabry-Perot Measurement. Knowing the equation of state of LiF and the measured velocity, we can derive the pressure at the surface as the detonation wave arrives.

Results

We ran detonation breakout profiles on two sets of detonators. The first set consisted of stored detonators which had uncertain environmental storage conditions. The second was a set of detonators, which we will label LTS (Long Term Storage), which have been stored under known environmental conditions.

The detonation profiles for one set of data (non-LTS) at varying distances from the bridgewire is shown in Fig.4.

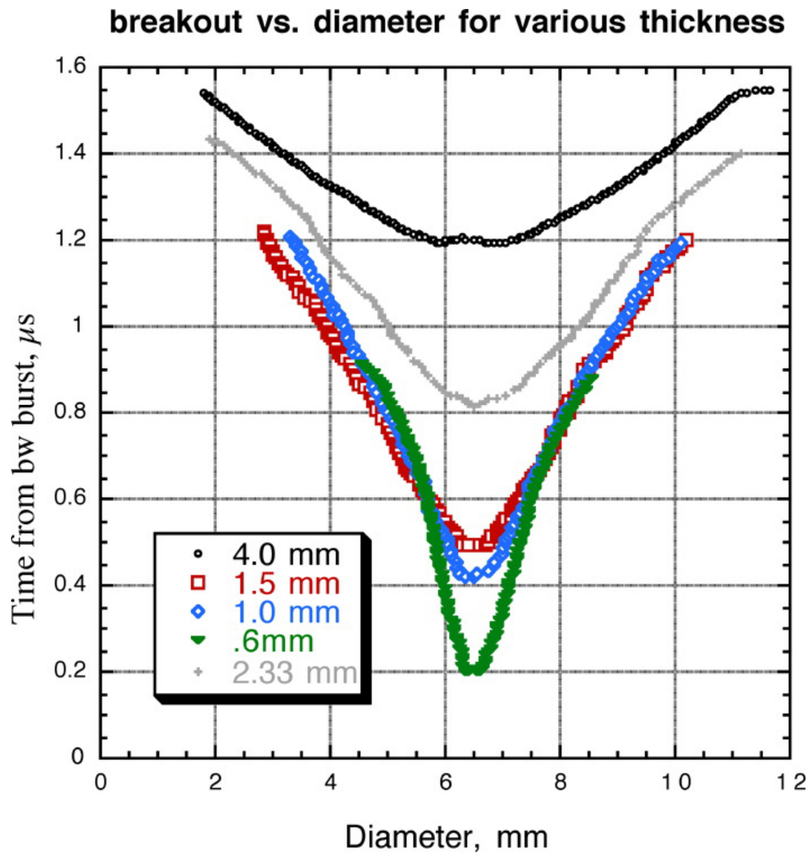

Fig. 4. Breakout profile for varying distances from the bridgewire for one series of stored detonators.

The LTS detonator series data agreed with and plotted into the above data very nicely. This may imply, if aging effects due to quite different environmental storage conditions are noticeable in these measurements, that the unknown storage conditions were probably quite similar to the LTS detonator conditions.

Several interesting things can be obtained from this data. A plot of the on-axis arrival time vs. time from burst (Fig. 5) shows that the detonator is not in full detonation until greater than about 3.0 mm distance from the bridgewire. Later we will show Fabry-Perot data that will verify this. Comparing the distance vs. time plot with the curve that would be expected from the PETN coming promptly to full detonation velocity, we can derive a "dwell" time for the detonator. We can derive this time from Fig. 5 and find it is on the order of 250 ns. Full detonation velocity for PETN at .93 gm/cc is 5.26 mm/μs as derived from the empirical expression,

$$\mathbf{D = 3.19 + 3.7(\rho - 0.37)} \quad [2] \qquad (1)$$

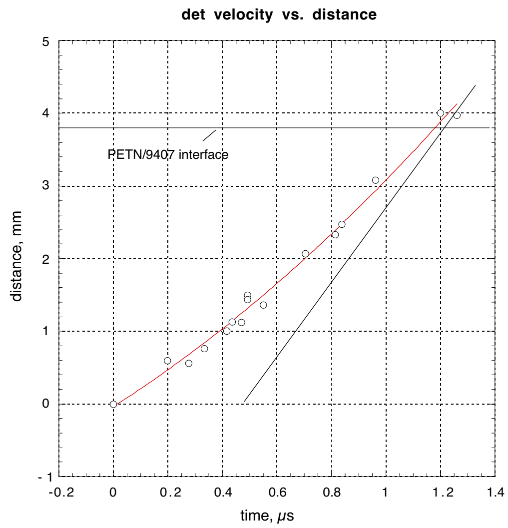

Fig. 5. Distance vs. time plot for breakout on axis. The straight line is the slope of fully detonating PETN of .93 gm/cc density.

By analyzing this breakout data and plotting results on a polar plot (with 0 degrees on the axis of the detonator) we can derive the shape of the detonation wave at various distances during formation and propagation of the wave. At a time of .2 μs after bridgewire burst we see (Fig. 6) that the wave deviates substantially from being spherical. As the wave propagates further and goes to full detonation the wave front becomes more spherical and by the time it reaches the PBX-9407 it is mostly spherical.

Fig. 7 shows a construction of the detonation front from our data .2 μs after burst overlayed on roughly the same scale as one of the framing camera shots from the bridgewire bursts in water experiments. This data can be fit by two spherically expanding detonation waves located approximately 300 μm from the surface of the bridgewire and 50 μm either side of the axis. This is, of course, only an approximation but may be reasonable given the data on these bridgewires bursting in water taken by Wilkins et al[1] where

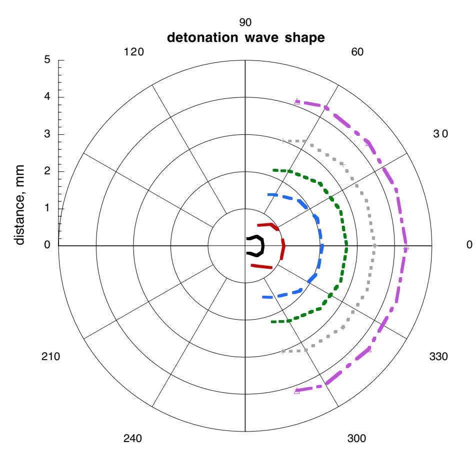

Fig. 6. The detonation wave shape as a function of distance from the bridgewire. Zero degrees is on the axis of the detonator.

they discovered the burst occured first where the bridgewire entered the solder balls. This explanation is a possibility since the aged detonators seem to burst fairly consistently near the solder balls as seen in Fig. 7, and the area where initiation appears to form is one in which the two shock waves from the two distinct burst points collide and reinforce, causing a higher pressure.

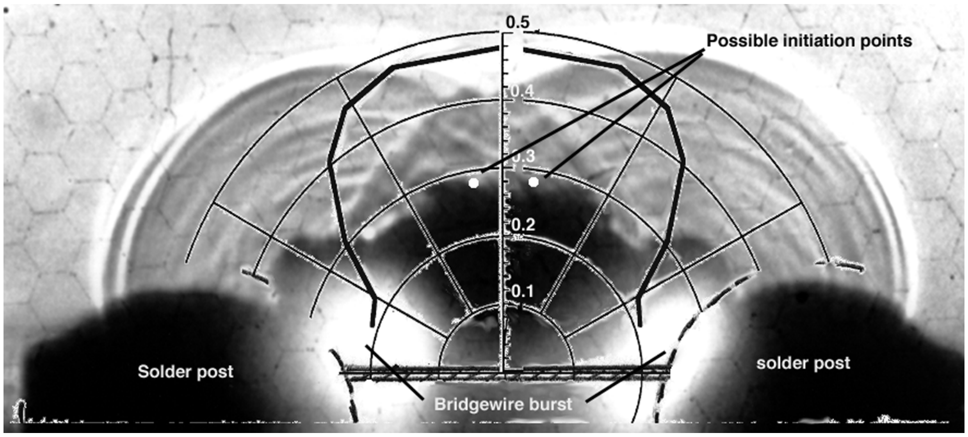

Fig. 7. The detonation wave front .2 μs after burst superimposed on a framing shot of a bridgewire burst in water (Wilkins et al). The vertical scale is in millimeters and the angle axis is marked in 30° intervals.

We cut the caps off several detonators , removed the PETN to expose the bridgewire and then fired them. We see similar results as those in the Wilkins experiments (Fig. 8), thus verifying our batches of detonators had bridgewires behaving similarly.

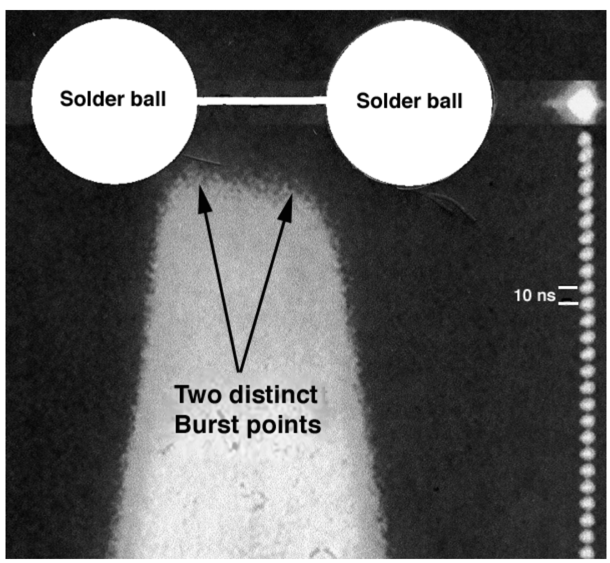

Fig. 8. A streak record of a bridgewire burst showing two distinct burst points toward the solder balls. Solder ball representation is just for horizontal scale here. Dots to the right are 10 ns apart.

We took one shot at a cut surface 0.6 mm from the bridgewire at high magnification. The streak record of the breakout at the PETN surface for this shot is shown in Fig.9. There is a region of first breakout that is relatively flat, perhaps tilted slightly toward the comb marks on the film. This region is about 160 μm wide. This is consistent with what we might expect from two detonation points, 300 μm below the surface and offset from the axis by 50 μm on each side (the same as shown in fig. 6). Note the breakout is not very sharp in Fig. 9. This may be due to the granular nature of the PETN.

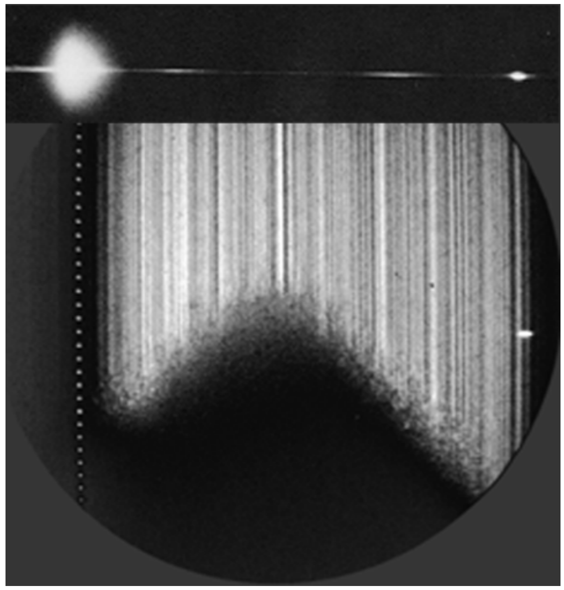

Fig. 9. A high magnification streak record of the detonation break out at 0.6 mm from the bridgewire. At top is a scaling setup shot to gauge the bridgewire distance.

Fabry Perot measurements were made on five samples at the center of the detonator on the cut surface at distances varying from 0.75 to 3.98 mm from the bridgewire. Fig. 10 summarizes the results of the interface velocity measured by this technique. The data agree well with our earlier results in that it appears the detonation reaches full strength at about 3.0 mm from the bridgewire.

Using the empirical expression,

$$\mathbf{Log\ P = -.03855 - 0.2916\ log\ x} \quad [3] \qquad \mathbf{(2)}$$

where P is initial shock pressure and x is the run distance to detonation in mm, we can estimate that the pressure at the initiation point (0.3 mm) should be about 0.68 Gpa for our run to detonation distance of about 2.7 mm assuming the pressure can be maintained during this time. We suspect the mechanism for maintaining the pressure during the run-to-detonation time is the deflagration of the PETN. Evidence that this is the case can be seen in Fig. 10 which is a plot of particle velocity vs. time. Very slow risetimes at the beginning of the initiation transitioning to steep risetimes is expected behavior of a deflagration to detonation transition. We are currently working on deriving the detonation pressure from our velocity data and these data will be the subject of a future paper.

Unfortunately, we were not able to get samples less than .5 mm thick to measure the peak pressure on this round of measurements. We believe we know how to do this now and plan to make this very interesting measurement next year.

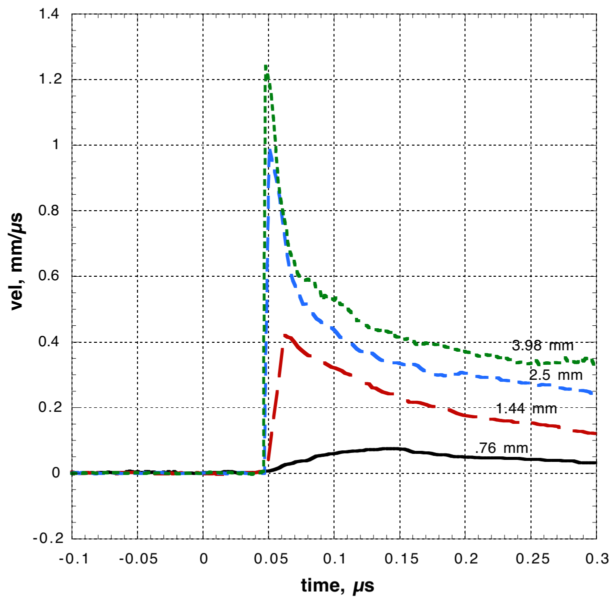

Fig. 10 Fabry velocity records as a function of time for various distances from the bridge. Data have been shifted in time so that the jump is at equal times for comparison.

Conclusions

We have established the techniques and gathered data that is unique in understanding the early detonation process in EBW detonators.

Data to date have all been taken on aged samples due to the lack of availability of detonators with new bridgewires and newly-pressed powder. We are currently in the process of obtaining new detonators to test.

We also plan to make breakout measurements in the perpendicular direction to the bridgewire. In addition, new samples cut to a thickness of 0.1 to 0.4 mm from the bridgewire will give us invaluable information as to the mechanism of initiation. At these distances we may be able to obtain data allowing us to determine the dynamics between deflagration and pressure effects in the buildup to detonation process.

These data are the first of their kind and have the potential for unlocking the presently unknown details of the EBW detonator initiation process.

References

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3. Dobratz and Crawford, *LLNL Explosives Handbook*, UCRL-52997, Lawrence Livermore National Laboratory, January, 1985, pg. 9-51.

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